Journal of Geoscience and Environment Protection, 2021, 9, 73-88
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Phytoremediation Potential of Vetiver Grass (Vetiveria Zizanioides) in Two Mixed Heavy Metal Contaminated Soils from the Zoundweogo and Boulkiemde Regions of Burkina Faso (West Africa)

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How to cite this paper: Ondo Zue Abaga, N., Dousset, S., & Munier-Lamy, C. (2021). Phytoremediation Potential of Vetiver Grass (Vetiveria Zizanioides) in Two Mixed Heavy Metal Contaminated Soils from the Zoundweogo and Boulkiemde Regions of Burkina Faso (West Africa). *Journal of Geoscience and Environment Protection, 9,* 73-88.
https://doi.org/10.4236/gep.2021.911006

Received: May 28, 2021
Accepted: November 20, 2021
Published: November 23, 2021

Abstract

In the agricultural regions of Burkina Faso, urban solid waste fertilizers were usually applied. This activity is likely to contaminate the soils and expose populations to serious diseases. This study aims to assess rate of heavy metal (Cd, Cu, Mn, Pb, Zn, Ni, Cr) contamination in both agricultural lixisol and vertisol and to evaluate the removal efficiency of heavy metals using Vetiver grass on different two mixed heavy metal contaminated soils. A pot experiment was conducted to compare the metal accumulation and overall efficiency of metal uptake by different plant parts (roots and shoots) on both tropical soils. After 3 and 6 months growing on laboratory conditions, Vetiver grass plants were harvested and heavy metal concentrations in shoot and root parts determined by Inductively Coupled Plasma - Atomic Emission Spectroscopy. The results indicate that at 3 and 6 moths, the shoot and root concentrations of heavy metals in Vetiver grass harvested in lixisol were higher than vertisol. For different plant parts, all metal concentrations were higher in root than in shoot, except Cu and Pb. At the 3 and 6 months, the BCF values > 1 for Cd, Cu and Zn in both soils showed Vetiver grass as an effective phyto-stabilizer for these metals. However, the TF values > 1 for Cd (lixisol), Mn, Zn Ni and Cr (vertisol) indicated the efficiency of Vetiver for phytoextraction. The results of this study showed that Vetiver is more effective in lixisol, but it can be used for remediation of both studied tropical soils from agricultural region of Burkina Faso. Nevertheless, considering the special limitations of the experimental conditions, further field monitoring is necessary to demonstrate the phytoremediation efficiency of Vetiver in agricultural soils under the climatic conditions of Burkina Faso.

Keywords

Vetiver Grass, Heavy Metals, Lixisol, Vertisol, Phytoextraction, Phytostabilization, Contamination

1. Introduction

Over these last years, soil contamination has received much global attention as it instigates considerable risks to both human health and the environment (Doran, 2002; Azam, 2016; Gómez-Sagasti et al., 2016). Anthropogenic sources of soil contamination may include both organic (pesticides, dioxin, poly-chlorinated biphenyl, halogen) and inorganic (metals and radioactive materials) components (Storelli, 2008; Ali & Khan, 2017). The major components of inorganic pollutants are heavy metals and metalloids, such as chromium (Cr), manganese (Mn), nickel (Ni), copper (Cu), zinc (Zn), cadmium (Cd), lead (Pb), mercury (Hg) and arsenic (As) (Barakat, 2011; Khan et al., 2011). Generally, the term heavy metal is widely used to indicate a group of natural metals in the periodic table with an elemental density > 5 g/cm^3 and atomic number > 20, often non-biodegradable and persistent in soils over a long duration (Bradl, 2005; Gomes, 2012; Ali & Khan, 2018). Heavy metals are released into the environment by human activities via industrial and agricultural practices and disposal of urban sewage sludge (Khan, 2005). Some heavy metals, such as Cu, Zn, Fe and Mn, are essential soil micronutrients required by living organisms in trace amounts for biological metabolic processes (Pilbeam & Barker 2007), and others heavy metals like Cd, Pb, Cr, Hg and As are non-essential for the growth of living organisms. However, all heavy metals are hazardous to human health as it easily bio-accumulated via the food chain due to soil-to-plant transfer of metals (Khan, 2005; Storelli 2008; Martin & Griswold 2009; Clemens & Ma, 2016; Ali et al., 2019).

Soil rehabilitation seems necessary in order to avoid human health problems linked to soil pollution. Several physical, chemical and biological assisted methods have been tested to clean up contaminated heavy metals in soils (Garbisu & Alkorta, 2003; Ghosh & Singh, 2005; Rahman et al., 2016). However, all of these strategies are expensive, extremely complicated and destructive to the natural ecosystem. Nonetheless, phytoremediation has evolved to be an alternative biological assisted method that is cost-effective, non-destructive and environmentally friendly approach for heavy metals soil decontamination (Glass, 2000; Ali et al., 2013; Mahar et al., 2016). As a consequence, phytoremediation is considered an innovative, economical and environmentally compatible method for heavy metals remediation (Antiochia et al., 2007). Phytoremediation is a technology that transfers pollutants from soils and sediments to the plant tissues without soil structure degradation and soil productivity decrease (Lombi et al., 2001). Heavy metal uptake by plants is dependent to soil metal concentration, soil nature and is also affected by plant physiology (Chen et al., 2004).

Somme plant species have great potential to accumulate metals in both shoot and root (Neisi et al., 2014). Vetiver grass, Vetiveria zizanioides (Linn.) Nash is one of the most promising plants due to its fast growing, deep and extensive root system, high tolerance to environmental stress such as extreme fluctuations of temperature (22˚C - 60˚C), soil pH (3.0 - 10.5), and most importantly high tolerance to heavy metal stress (Danh et al., 2009; Truong & Danh, 2015; Gnansounou et al., 2017; Darajeh et al., 2019; Ng et al., 2019). Vetiver grass originated in the Indian sub-continent can also be found throughout the tropical and subtropical regions of Africa, Asia, America, Australia, and Mediterranean Europe (Maffei, 2002). Vetiver grass has a very high tolerance for organic and inorganic pollutants and has been used for remediation of soils polluted by pesticides (Ondo Zue Abaga et al., 2014a), phenol, nuclear wastes and protozoa (Singh et al., 2008) and heavy metals (Truong & Danh, 2015; Suelee et al., 2017; Ng et al., 2020).

Limited data are available about soil remediation especially using Vetiver grass in Africa in general, and particularly in Burkina Faso. Nevertheless, Vetiver grass, Vetiver zizanoides has been studied for stabilization and biodegradation of pesticide in the agricultural cotton-soils of Burkina Fasol (Ondo Zue Abaga et al., 2014a) and for phytoaccumulation of both Cu and Cd in agricultural soil (Ondo Zue Abaga et al., 2014b). Therefore, the objectives of this study were to evaluate the accumulation trend and efficiency of metal uptake by Vetiver grass from two mixed form Cd, Cu, Mn, Pb, Zn, Ni and Cr contaminated soils collected in agricultural region of Brukina Faso. Soil nature influence was investigated on metal bioaccumulation in both root and shoot of Vetiver grass in the laboratory conditions.

2. Material and Method

2.1. Presentation of the Study Area

Located in the Sudanian and Sudano-sahelian zones of Burkina Faso, more precisely in the provinces of Zoundweogo and Boulkiemde, it contains two (2) experimental sites of cotton zone (**Figure 1**). They are Kaïbo, between latitude 11˚49' North and longitude 05˚56' West, and Saria between latitude 12˚16' North and longitude 02˚09' West, respectively. The study area is under a dry tropical climate which alternates between a short rainy season and a long dry season. The country has three distinct climatic zones: the Sahel region in the north receiving less than 600 mm average annual rainfall, the North-Sudanian zone in center with an average annual rainfall between 600 and 900 mm; and the South-Sudanian zone in the south with an average annual rainfall over 900 mm (UNDP, 2021). Annual average temperatures in Burkina Faso range between 27˚C - 30˚C, with monthly averages ranging from 14˚C - 15˚C (USAID, 2017). The two experimental stations Kaïbo and Saria are characterized by Vertisol and Lixisol

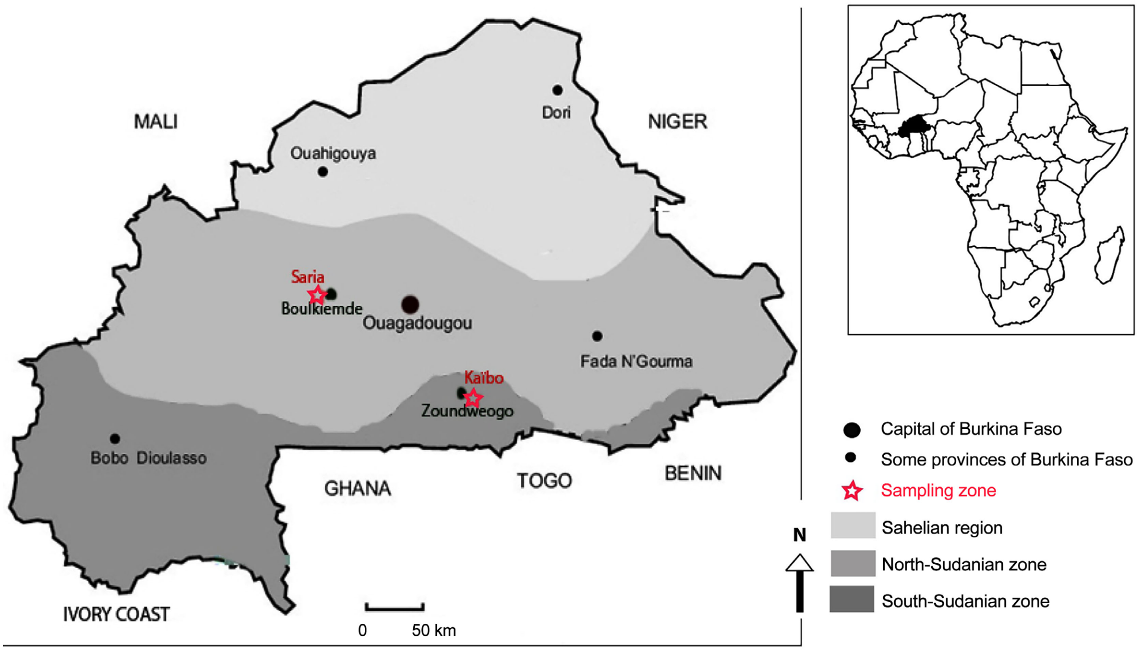

Figure 1. The geographical location of sampling zone in the study area.

(IUSS Working Group WRB, 2006), respectively. The geological formations of the study area are composed of Precambrian rocks generally characterized by granitic gneisses, and north to northeasterly trending belts of metasediments and metavolcanics (Schlüter, 2008).

2.2. Soil Samples and Physic-Chemical Properties Characterization

Two experimental soils were taken from the soil surface (0 - 20 cm) of two experimental stations, Saria and Kaïbo, in the cotton zone of Burkina Faso (**Figure 1**). The soil samples were prepared and analyzed as described by Ondo Zue Abaga et al. (2014a). The samples soils were air-dried, sieved to 2-mm, and sent for characterization at the soil analysis laboratory of INRA-Arras in France. The following analyses were carried using the European soils quality standards given in brackets: particle size distribution (NF X 31–107), pH (NF ISO 10390), total organic carbon (NF ISO 10694), N (NF ISO 13878), cation exchange capacity (CEC) (NF X 31–130), and the total major elements (NF X 31–147). A 40-mL volume of the clay fraction (0 - 2 μm) obtained from 6 g of soil per 500 mL of water (soil/solution: 1/83.3) was used to determine the mineralogical composition of the clay. Clay mineral characterization was performed using a Broker® D8 diffractometer (Karlsruhe, Germany), with Co Kαradiation. Diffractograms were recorded from 3˚ to 40˚ 2θ, with a step scan of 0.035˚ 2θ and time per step of 3 s on two preparations: a deposit oriented toward air-dried clays and a deposit oriented toward saturated clays at ambient temperature for 24 h, in ethylene glycol (EG) vapors (Mosser-Ruck & Cathelineau, 2004).

Total metal (Cd, Cu, Mn, Pb, Zn, Ni, Cr) concentrations were determined using a flame atomic absorption spectrometer (Varian 702-ES). A graphite furnace atomic absorption spectrometer (Varian 220Z model) was used to measure the Cd concentrations below 1 mg/L. The limit of quantification was 0.10 mg/kg dry soil for Cd, 1 for Cu and 4.22 mg/kg dry soil for Mn, Pb, Zn, Ni and Cr. In soil, total metal concentrations do not necessarily correspond with metal bioavailable. Bioavailability is the proportion of the total metals that are available for incorporation into biota (bioaccumulation). It is the interest of bioavailable fraction studies of the major metals listed by the Environmental Protection Agency (EPA) of United States (McKinney & Rogers, 1992). The bioavailable fractions of heavy metals were evaluated using a $MgCl_2$ 0.1 M extractant (Meers et al., 2007). Heavy metals were extracted from 1 g of soil mixed with 40 mL 0.1 M $MgCl_2$ in a 50-mL polycarbonate vial. The soil suspensions were agitated on a rotary shaker for 1 h and centrifuged for 10 min at 2900 g. The supernatant filtered using Whatman filters (0.45 μm pore size) received 4 ml of 69% nitric acid before the analysis. The heavy metals concentrations were determined by Inductively Coupled Plasma - Atomic Emission Spectroscopy (ICP-AES, Varian 702-ES model) as above with a limit of quantification of 0.25 mg/kg dry soil.

The soil characteristics are given in **Table 1**. The soil texture was loamy clay for vertisol and sandy loam for lixisol according to Jamagne (1967). The organic carbon (OC) content was higher in vertisol (0.95%) and the pH slightly less acidic (pH 6.1) than in lixisol (OC 0.43% and pH 5.8) (**Table 1**). Vertisol contained more Al_2O_3 (9.8%) and Fe_2O_3 (4.6%) than lixisol (Al_2O_3, 3.5%; Fe_2O_3, 1.1%). In the vertisol, clays mineral were more abundant: chlorite (4%), Illite (45%), Interstratified Illite/Chlorite (4%), kaolinite (31.5%) and smectite + interstratified Illite/smectite (15.5%) than in lixisol with only Illite (21%) and a low CEC kaolinite (79%). These results could explain the most important CEC in vertisol (10.5 $cmol \cdot kg^{-1}$) compared to lixisol (<1 $cmol \cdot kg^{-1}$).

The results of heavy metals analyses indicated that total Cu, Mn, Zn, Ni and Cr concentrations were significantly ($P < 0.05$) higher in vertisol compared to lixisol (**Table 1**). For Cd, and Pb, no significant difference was observed between the two soils. However, the total exchangeable metal was similar in both soils for Cd, Mn, Pb, Zn, Ni and Cr. Only the extractable-Cu concentration was significantly higher ($P < 0.05$) in lixisol than in vertisol. Finally, the soil content of available trace metals (Cu, Mn, Pb, Zn, Ni, Cr) depends on different factors, including the content of organic carbon (MacFarlane et al., 2003), clay content and CEC (Baran et al., 2014; Nunes et al., 2014). These observed values may be attributed to the clay, organic carbon, CEC and oxide (Al_2O_3 and Fe_2O_3) contents (**Table 1**) higher in vertisol than in lixisol and promoted the retention of metals, especially of Cu. These results are in agreement with those of Nunes et al. (2014).

2.3. Pot Experiments

2.3.1. Experimental Design and Soil Treatments

The experiments were conducted out under controlled conditions in a phytotronic chamber located at Nancy, Interdisciplinary Laboratory of Continental

Table 1. Physico-chemical properties of the experimental soils. The Newman-Keuls statistical validity test was used for significant differences of each metal content among both experimental soils at the 95% level of confidence. Significant differences were noted by $^*P < 0.05$ (significant), $^{**}P < 0.01$ (highly significant), $^{***}P < 0.001$ (very highly significant) and ns (not significant).

Characteristics	*Vertisol (VS)*	*Lixisol (LS)*
Soil texture	loamy clay	sandy loam
Sand (%)	25.9	68.6
Silt (%)	44.8	21.6
Clay (%)	29.3	9.5
Soil pH	6.1	5.8
Organic carbon (OC) (%)	0.95	0.43
Al_2O_3	9.8	3.5
Fe_2O_3	4.6	1.1
Cation exchange capacity (cmol/kg)	10.5	<1
Clay minerals (%)		
chlorite	4	0
Illite	45	21
Interstratified Illite/Chlorite	4	0
kaolinite	31.5	79
smectite + interstratified Illite/smectite	15.5	0
Metal contents (mg/kg): Total (available)		
Cadmium (Cd): ns (ns)	2.80 ± 0.08 (2.53 ± 0.11)	2.86 ± 0.12 (2.65 ± 0.01)
*Copper (Cu): ** (**)*	136.27 ± 5.46 (5.90 ± 1.44)	103.78 ± 3.47 (37.11 ± 0.21)
*Manganese (Mn): *** (ns)*	619.52 ± 77.44 (10.53 ± 1.16)	154.88 ± 0.30 (14.92 ± 0.15)
Lead (Pb): ns (ns)	17.88 ± 2.51 (2.84 ± 0.05)	12.15 ± 2.24 (2.71 ± 0.01)
*Zinc (Zn): ** (ns)*	51.58 ± 3.82 (1.62 ± 0.10)	28.14 ± 0.75 (1.50 ± 0.08)
*Nickel (Ni): ** (ns)*	36.71 ± 2.92 (2.23 ± 0.12)	16.29 ± 1.18 (1.80 ± 0.01)
*Chromium (Cr): ** (ns)*	87.12 ± 10.42 (0.58 ± 0.03)	45.43 ± 3.11 (0.59 ± 0.01)
Mean ± standard deviation		

Environments, University of Lorraine in France, under the following conditions: 24˚C/16˚C temperature at day/night, 70% humidity, 12 h day, 22.7×10^3 cd m^{-2} light intensity. Top soil (0 - 20 cm depth) collected from two experimental stations in the cotton zone of Burkina Faso and experimental soils were air-dried, sieved through 2 mm mesh and mixed to obtain a homogenous soil sample. The soils samples underwent a preliminary physico-chemical soil assessment (Table 1) prior to the preparation of pot experiment. Vetiver plants were transplanted into plastic pots containing 1 kg of 2 mm-sieved lixisol or vertisol. Each pot received a single three-month old Vetiver plant with leaves and roots cut at 14 cm and 5 cm length, respectively. For both soil types, the unplanted control pots were monitored under the same conditions as the planted pots throughout the

6-month period of the experiment. The soil moisture content was maintained at 60% of the field water capacity by adding distilled water every three days. All samples were fertilized by adding a mixture of N/P/K (3/1/1) every 2 weeks (Chen et al., 2004). The study was conducted under the randomized design with three replications. Plants and soils were sampled three (T3) and six months (T6) after Vetiver growth for analyses.

2.3.2. Heavy Metals Analyses and Statistical

At 3-month (T3) and 6-month (T6) of experiment, all freshly harvested plants were washed with tap water then rinsed several times with deionized water to remove any adhering soil particles especially at root part. Shoots and roots tissue, previously air-dried for 72 h, were oven-dried at 60˚C for 48 h. The dry biomass was weighed, ground to a fine powder (Retsch ZM 1) and sieved through a 2-mm mesh. For metal extraction, the microwave digestion method used and 200 mg of plant material was digested using an acid mixture of 69% HNO_3 and 30% H_2O_2 (2:1 v/v) into a pressure-resistant PTFE (polytetrafluoroethylene) vessel (Saydut, 2010; Güven & Akinci, 2011). Metal-concentrations (Cd, Cu, Mn, Pb, Zn, Ni, Cr) in plant tissue were analyzed by Inductively Coupled Plasma - Atomic Emission Spectroscopy (ICP-AES, Varian 702-ES model) as above with a limit of quantification of 0.63 mg/kg dry weight.

All experimental data analyzed by performing two-ways analysis of variance (ANOVA), using statistical XLSTAT software, to evaluate the metal accumulation in Vetiver growing under different types of soils. The means of different concentrations were compared by Newman-Keuls's least significant difference tests at the 95% level of confidence.

2.3.3. Determination of Phytoremediation Quotient

The ability of Vetiver grass for metal accumulation and translocation upwards were evaluated by determining the biological accumulation coefficient (BAC), biological concentration factor (BCF) and translocation factor (TF) (Yoon et al., 2006; Ali et al., 2013; Ng et al., 2020), as follows:

BAC = Concentration of heavy metals in tillers/Concentration of heavy metals in soil;

BCF = Concentration of heavy metals in roots/Concentration of heavy metals in soil;

TF = Concentration of heavy metals in shoot/Concentration of heavy metals in roots.

3. Results and Discussion

3.1. Heavy Metal Concentration in Shoots and Roots of Vetiver

Table 2 shows the concentration of Cd, Cu, Mn, Pb, Zn, Ni and Cr accumulation in roots and shoots for Vetiver grass. Generaly, Vetiver grass takes up heavy metals in vertisol and lixisol. Metal concentrations in both the roots and shoots did not increased with time (between 3 and 6 months Vetiver growing), but were

Table 2. Heavy metal concentrations in the roots and shoots of Vetiver (mg/kgdry matter) harvested at T3 and T6 months.

Samples	Cd	Cu	Mn	Pb	Zn	Ni	Cr
			Shoots (mg/kg DW)				
VS_T3	1.53 ± 0.88^{b}	23.15 ± 12.30^{b}	103.62 ± 39.13^{b}	6.08 ± 6.08^{a}	23.66 ± 2.91^{a}	67.98 ± 20.33^{a}	134.45 ± 10.43^{a}
LS-T3	22.16 ± 9.81^{a}	331.83 ± 130.94^{a}	425.78 ± 110.67^{a}	1.72 ± 0.62^{a}	29.25 ± 9.83^{a}	65.23 ± 55.84^{a}	133.0 ± 118.18^{a}
VS_T6	2.25 ± 0.87^{b}	44.08 ± 15.93^{b}	284.17 ± 4.02^{ab}	0.83 ± 0.07^{a}	22.83 ± 10.53^{a}	126.88 ± 63.24^{a}	227.50 ± 108.9^{a}
LS-T6	21.28 ± 11.38^{a}	304.71 ± 94.38^{a}	386.67 ± 129.93^{a}	0.96 ± 0.07^{a}	33.46 ± 12.20^{a}	135.04 ± 53.71^{a}	245.83 ± 92.08^{a}
			Roots (mg/kg DW)				
VS_T3	4.55 ± 1.11^{b}	145.19 ± 79.55^{c}	124.19 ± 116.97^{a}	2.43 ± 0.46^{a}	25.50 ± 4.66^{a}	5.06 ± 1.77^{a}	4.72 ± 1.75^{a}
LS-T3	15.82 ± 2.33^{a}	709.64 ± 227.5^{ab}	178.90 ± 56.72^{a}	2.46 ± 1.19^{a}	24.87 ± 5.26^{a}	3.07 ± 1.04^{ab}	3.27 ± 1.57^{a}
VS_T6	6.42 ± 1.31^{b}	499.17 ± 72.68^{b}	151.67 ± 6.41^{a}	2.29 ± 0.31^{a}	24.04 ± 4.13^{a}	3.58 ± 0.75^{ab}	4.50 ± 1.15^{a}
LS-T6	14.88 ± 4.11^{a}	637.50 ± 83.88^{a}	171.67 ± 36.26^{a}	3.00 ± 2.20^{a}	27.59 ± 8.58^{a}	1.84 ± 0.31^{b}	2.42 ± 1.15^{a}

Mean ± standard deviation and for shoots and roots, value in the same column with different superscript are significantly different at $P < 0.05$.

depended on the soil type. At 3 months, Vetiver grass tended to accumulate higher concentrations of heavy metals on lixisol. Vetiver growing on lixisol recorded significantly higher ($P < 0.05$) accumulation of Cd, Cu and Mn in both shoots (22.16, 331.83 and 425.78 mg/kg) and roots (15.82, 709.64 and 178.9 mg/kg) compared to the Vetiver growing on vertisol (**Table 2**). For Mn, Pb, Zn, Ni and Cr accumulation in shoot and root parts, not significant difference were found between both experimental soil types. The accumulation especially for Cd, Cu and Mn were significantly greater for lixisol than vertisol in relation to the negligible lixisol CEC compared to the vertisol CEC (**Table 1**). The highest organic carbon content increases the CEC of the vertisol which retains metallic elements and reduces significantly the heavy metals bioavailability. These findings are in agreement with Ondo Zue Abaga et al. (2014b) study that reported that Cu and Cd adsorption were significantly higher in vertisol compared to lixisol. However, at 3 an 6 months, accumulate concentrations of Ni and Cr were higher in shoots than in roots of Vetiver grass in both vertisol and lixisol (**Table 2**). In root part, higher Ni and Cr accumulation was found in vetiver growing on vertisol compared on lixisol. This result may be attributed to the total initial Ni and Cr concentrations significanty higher in vertisol than lixisol (**Table 1**). The findings were in line with previous studies that amount of metals uptake by plant root increased as initial concentration of heavy metals increased (Roongtanakiat & Chairoj, 2001; Ghosh & Singh, 2005). This suggests that Vetiver grass can be considered like a rhizofiltrator for Ni and Cr due to higher absorption of most heavy metals by root at different metal concentrations (Truong, 2000).

For both types of soil, time did not seem to have a significant impact in metals concentrations stored in Vetiver shoots and roots (**Table 2**). Heavy metal adsorption and their accumulation in Vetiver grass were important following a growth period of three months. Whereas, the accumulation was lower for a growth period ranging from 3 to 6 month, probably due to the weak concentrations of initial metal-bioavailable in soils. This could be related to our experimental conditions such as soil weight (1 kg per pot) combined with the experiment duration (6 months) which may constitute limiting factors in this study. Generally, phytoremediation studies of heavy metal contaminated soils using Vetiver grass are often carried out with at least 2 kg of soil per pot and the experiment duration between 2 and 3 moths (Jampasri & Saeng-Ngam, 2019; Ng et al., 2020), and Vetiver growth is often by nutrients, EDTA to promote metal uptake and accumulation in plant tissues (Aksorn & Chitsomboon, 2013; Ng et al., 2016). Under these experimental conditions, plant growth is fast, its root density becomes more important and increase surface area for metal absorption by plant roots (Suelee et al., 2017).

Although the metal absorption by Vetiver grass is shown in the both studied soils, the highest concentrations were found in plant tissues grown on lixisol for T3 and T6, in the following order Cu > Mn > Zn > Cd > Cr > Ni > Pb in roots and Mn > Cu > Cr > Ni > Zn > Cd > Pb in shoots (**Table 2**). The observed variation in the amount of metals accumulated by Vetiver in their various parts in the various soils is an indication that metal uptake by Vetiver is primarily dependent on the soil quality and metal concentrations in their habitual soil environment (Chunilall et al., 2005). Indeed, metal adsorption in soil increases with high soil properties such as organic carbon, clay minerals content, Al_2O_3, Fe_2O_3 and CEC (Covelo et al., 2007; Cerqueira et al., 2011) higher in vertisol compared to lixisol (**Table 1**) reducing their bioavailability. This would explain the lower metal content accumulated in vetiver generally harvested in vertisol. Thus, Vetiver is shown to be more effective for lixisol remediation.

3.2. Translocation and Bioaccumulation Factors

The association of the different heavy metals accumulated from the tropical soils into the roots and shoots for Vetiver grass, in terms of BAC, BCF and TF are summarized in **Table 3**. A critical value greater than one (>1) for plants' BAC, BCF and TF is used to evaluate the potentials of plant species for phytoremediation method such as stabilization and extraction processes (Yoon et al., 2006; Cui et al., 2007; Li et al., 2007). The results showed that Vetiver had BAC > 1 at three months for Cu, Mn and Cr mainly in lixisol (LS), and at six months for Cd, Cu, Mn, Zn, Ni and Cr in both soil types, with the higher values in the lixisol 14.9, 9.5, 1, 1.5, 5.9 and 2, respectively. These results indicate that Vetiver grass can be used for Cd, Cu, Mn, Zn, Ni and Cr phytoremediation, especially in the lixisol. Plants with well-developed cellular mechanisms for heavy metal detoxification and tolerance (BAC > 1) are used as an indicator of high heavy metals accumulator plant species (Ghosh & Singh, 2005).

A good phytoremediator species possesses BCF value of greater than 1 (Zhang et al., 2002). Noticeably, after six months growing, the BCF values were greater than 1 for Cd and Cu in the both soils and for Zn in lixisol. The observed values indicate a great absorption of Cd, Cu and Zn in the lixisol, with the higher BCF

Table 3. Biological Accumulation Coefficient (BAC), Biological Coefficient Factor (BCF) and Translocation Factor (TF) of Vetiver grass sampled after 3 months (T3) and 6 months (T6) growing in the vertisol (VS) and lixisol (LS).

Metal	Soil type	BAC		BCF		TF	
		T3	T6	T3	T6	T3	T6
Cd	VS	nd	**2.0 ± 0.3**	nd	**3.4 ± 0.9**	0.3 ± 0.1	0.4 ± 0.2
	LS	nd	**14.9 ± 6.8**	nd	**11.8 ± 4.7**	**1.4 ± 0.7**	**1.4 ± 0.5**
Cu	VS	0.6 ± 0.3	**3.5 ± 0.8**	**1.2 ± 0.7**	**8.1 ± 1.8**	0.2 ± 0.1	0.1 ± 0.0
	LS	**6.1 ± 1.8**	**9.5 ± 2.1**	**9.6 ± 3.7**	**14.5 ± 3.1**	0.5 ± 0.3	0.5 ± 0.1
Mn	VS	0.1 ± 0.0	0.2 ± 0.0	0.2 ± 0.1	0.1 ± 0.0	**1.2 ± 0.6**	**1.9 ± 0.1**
	LS	**2.2 ± 0.6**	**1.0 ± 0.3**	**1.2 ± 0.4**	0.6 ± 0.1	**2.4 ± 0.2**	**2.4 ± 1.3**
Pb	VS	nd	0.0 ± 0.0	nd	0.1 ± 0.1	0.6 ± 1.1	0.1 ± 0.2
	LS	nd	0.1 ± 0.1	nd	0.2 ± 0.3	0.2 ± 0.4	0.0 ± 0.1
Zn	VS	nd	0.4 ± 0.2	nd	0.5 ± 0.2	**1.0 ± 0.3**	**1.0 ± 0.6**
	LS	nd	**1.5 ± 0.8**	nd	**1.4 ± 0.7**	**1.2 ± 0.3**	**1.3 ± 0.5**
Ni	VS	nd	**2.2 ± 0.9**	nd	0.1 ± 0.1	**15.8 ± 10.1**	**34.5 ± 11.3**
	LS	nd	**5.9 ± 2.7**	nd	0.1 ± 0.0	**23.4 ± 21.6**	**75.5 ± 31.3**
Cr	VS	**1.1 ± 0.5**	**1.33 ± 0.7**	0.1 ± 0.0	0.0 ± 0.0	**34.9 ± 25.9**	**50.7 ± 18.3**
	LS	nd	**2.0 ± 0.9**	nd	0.0 ± 0.0	**45.5 ± 38.6**	**121.5 ± 70.7**

values of 11.8, 14.5 and 1.4, respectively (Table 3), exhibiting firstly that the Cu accumulation was higher than the Cd, Zn and secondly that the metal accumulation potential of Vetiver was higher in the lixisol than in the vertisol. These heavy metals showed a preferential accumulation in the roots of Vetiver after their absorption from soils. In case of soil weight is more than 1 kg (case of our study), the more important root density of Vetiver would be more efficiency for metal accumulation due to increased surface area for metal absorption by plant roots (Suelee et al., 2017). Elevated concentrations of heavy metals in roots of plants species and low translocation into above ground parts (BCF) indicate their suitability for phytostabilization (Ghosh & Singh, 2005).

Translocation factor (TF) is the ratio that indicates the relative transportation of metals from roots to shoots of the plants (Mellem et al., 2012). TF values > 1 indicate the greater translocation of metals from root to the shoot part of the plant. In contrast, TF values < 1 mean that metals are largely store in the root part of plants (Mellem et al., 2012). High root to shoot translocation (TF > 1) as observed for Cd in the lixisol and for Mn, Zn, Ni and Cr in the both studied soils. These results showed the ability of Vetiver to translocate heavy metals to easily harvestable parts (shoots). Similar TF values were obtained at three and six months for Cd, Mn and Zn in the lixisol (1.4, 2.4 and 1.2) and in vertisol (0.3, 1.2 and 1.0), respectively (Table 3). Generally, metals such as Cd, Pb and Cu preferentially accumulate in roots and often show low TF values (Aksorn & Chitsomboon, 2013; Jampasri & Saeng-Ngam, 2019). However, in comparison with Ng et al. (2016), our study shows low metal translocation. This observation can be explained by the application of soil amendments EDTA, elemental S and N-fertilizer significantly increasing metal accumulation in the shoots in plant, with metal TF generally > 1.72 (Rahman et al., 2013; Ng et al., 2016).

Cadmium (Cd), Mn and Zn translocation decrease after three months growing of Vetiver. These TF values are lower compared to those of Ni (15.8 to 75.5) and Cr (34.9 to 121.5), with the highest TF being obtained in lixisol following a 6-month growth period. This result is an indication that Vetiver grass has vital characteristics to be used in phytoextraction (Malik et al., 2010). The observed high Ni and Cr translocation quotient may be attributed to well-developed metal detoxification mechanism based on sequestration in the tolerant plant species (Ghosh & Singh, 2005; Cui et al., 2007).

According to Yoon et al. (2006), a plant is considered as a hyperaccumulator of ETM when his translocation factor (TF) is greater than 1. Based on that definition, Vetiver can be considered as a hyperaccumulator of Cd in lixisol and Mn, Zn, Ni and Cr in both soil types, with a more important hyperaccumulation in lixisol. However, according to Baker & Brooks (1989), a plant is said to be a hyperaccumulator if it is capaple of storing in its aerial parts more than 100 mg/kgdry plant of Cd and As, 1000 mg/kg of Co, Cu, Cr and Pb, and 10000 mg/kg of Mn, Zn et Ni (Watanabe, 1997; Baker & Brooks, 1989). According to our results, none of the heavy metals accumulated in Vetiver shoots exceeds those limits. This finding could be explained by weak ETM concentrations in the soil sampled.

Despite the low accumulation of heavy metal found in the root and shoot, the observed values of BAC, BCF and FT showed that Vetiver exhibited varying levels of phytoaccumulation potentials. Results from the present study suggested that Vetiver grass could effectively act as phytostabilizer for Cd in vertisol and Cu in lixisol and vertisol with BCF values greater than 1 and TF values of less than 1. However, despite the experimental duration, Vetiver is more favorable for phytoextraction of Cd in lixisol and Mn, Zn, Ni and Cr in the both vertisol and lixisol due to TF > 1.

4. Conclusion

Vetiver grass (*Vetiveria zizanioides*) was found effective in heavy metals (Cd, Cu, Mn, Pb, Zn, Ni, Cr) accumulation in both studied tropical soils, but the rate of metal accumulation depends on the soil nature. Vetiver grass is a better accumulator of heavy metals in lixisol than vertisol at T3 and T6, in the order of Cu > Mn > Zn > Cd > Cr > Ni > Pb in roots and Mn > Cu > Cr > Ni > Zn > Cd > Pb in shoots, due to soil physic-chemical properties limiting the metal bioavailability in vertisol. In terms of different plant parts, at T3 and T6 plant growing, the shoots exhibited a strong tendency for greater uptake and accumulation of all heavy metals, except Cu and Pb with higher accumulation in roots than shoots. Vetiver grass may be considered as a promising Cd, Cu and Zn phyto-stabilizer due to its high BCF values of >1 in both soils. However, Vetiver is more favorable for phytoextraction of Cd in lixisol and Mn, Zn, Ni and Cr in vertisol due to high TF values > 1. Our study demonstrated that Vetiver grass can be considered as a suitable candidate for the remediation of both tropical soils contaminated with heavy metal under laboratory test conditions. Future research may need to investigate metal uptake mechanisms, accumulation and tolerance of Vetiver grass in natural conditions on agricultural soils in Burkina Faso in order to have additional data on the growth of Vetiver and its up-take metals capacity according to climatic seasons in this country.

Acknowledgements

This work was financially supported in part by a CORUS II Project and a Gabonese Government Fellowship. The authors thank the Botanical Garden of Montet (Villers-les-Nancy, 54 France) for material support and for providing the Vetiver plants. We also thank Paul SAVADOGO (INERA, Ouagadougou, Burkina-Faso) for providing the studied soils and Regine MOSSER-RUCK (GeoRessources, Nancy 54 France) for the clay mineralogical compositions.

The Author's Contributions

All authors contributed to the research design, analysis data, and the manuscript's writing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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